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IMPROVEMENT OF THE SYSTEM OF MODULAR INFLATED SHELLS BY MEANS OF PHYSICAL MODELLING

ROMUALD TARCZEWSKI*, WALDEMAR BOBER†

* Department of Structural Engineering, Faculty of Architecture
Wroclaw University of Technology
ul. B. Prusa 53/55, 51-317 Wroclaw, Poland
e-mail: romuald.tarczewski@pwr.wroc.pl, web page: http://tarczewski.arch.pwr.wroc.pl

† Department of Structural Engineering, Faculty of Architecture
Wroclaw University of Technology
ul. B. Prusa 53/55, 51-317 Wroclaw, Poland
e-mail: waldemar.bober@pwr.wroc.pl

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Summary. *The paper presents results of experimental research of modular inflated shells. Experiments carried out in the first phase showed that proposed connection between cushion modules has led to the creation of articulated joints and resulted in local instability. Thus, a new type of connection has been developed and new series of experiments have been carried out.*

1 INTRODUCTION

In the previous works[1,2,4], author introduced idea to form a large and complex pneumatic structure as a set of repeatable, modular inflated units with tensioned cables and with additional bars or without them. The core idea was to eliminate some disadvantages of traditional pneumatic structures.

Modular inflated shells present a class of spatially curved surface girders – single and double curved shells. They are composed of relatively small inflated cushions combined with cables and cross-braces. Their rigidity and loading ability are strongly related to the shape. Spatial curvature itself, is not a permanent, generic feature of the structure, but is achieved and maintained by means of post-tensioning, causing very large initial deformation. Post-tensioning is a way of integrating small elements as well as shaping the structure. Coupling of these operations raises the efficiency of solution. Thus, the final shape and properties of the structure are function of initial configuration and the course of post-tensioning process.

Presented structures can be applied for any type of building where large clear span is a challenge for designers as well as short time and low cost of erection. Self-erection is a convenient method of shaping both permanent and temporary, rapidly assembled covers for industrial buildings, warehouses, sport facilities, exhibition halls, field hospitals, temporary covers of building sites or for military applications such as deployable bridges.

Typical layout of modular inflated shell composed of cushions, cables and cross-braces is presented on Fig. 1.

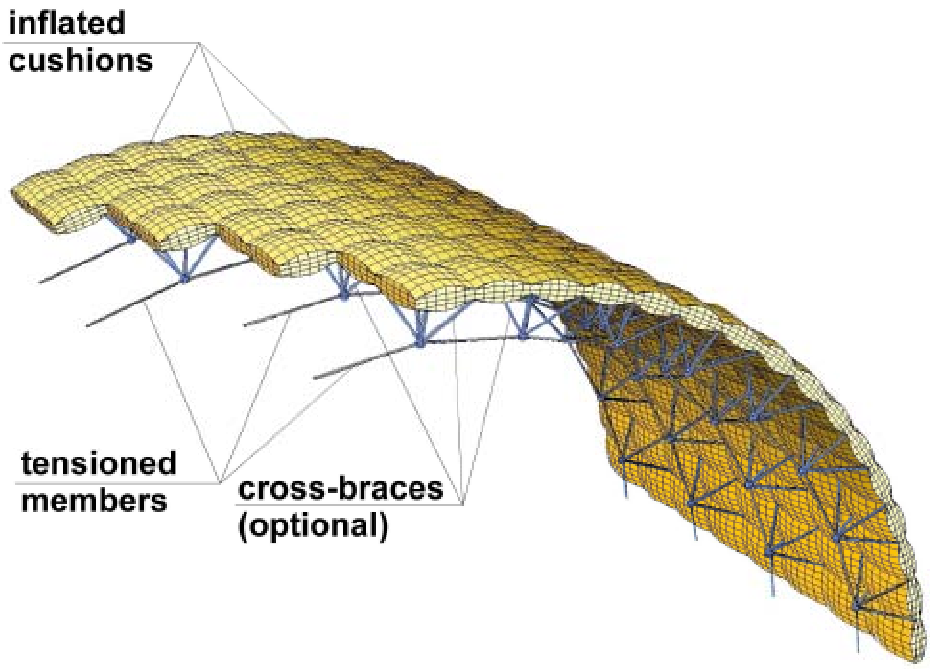

Figure 1: Typical layout of modular inflated shell

2 INITIAL EXPERIMENTAL RESEARCH

The presented system was tested using physical models[3]. The main purpose of carried out experiment was to verify realizability of modular inflated shells. It was assumed that the experiment would be mostly of qualitative not quantitative character. It was also assumed that the subject of the survey would be relation of elevation and shape to the shortening of distance between supporting points.

2.1 Description of the models

The modular inflated elements were prepared with use of inflated cushions widely used in popular sport equipment. Each cushion forms a single modular element. These cushions are made of 0.30 mm PVC foil. Nominal dimensions are: 89.5×89.5×21.5 cm. Cushions are equipped with internal diaphragms, reducing deformation after inflation. Diaphragms do not obstruct airflow inside cushion. Air valve is placed on side face of the cushion. The cushions have been adapted for the purpose of experiment by means of addition of connectors, i.e. fabric belts, touch fastener strips and connectors for tensioned members and cross-braces. Figure 2 presents details of inflated cushion used in experiment.

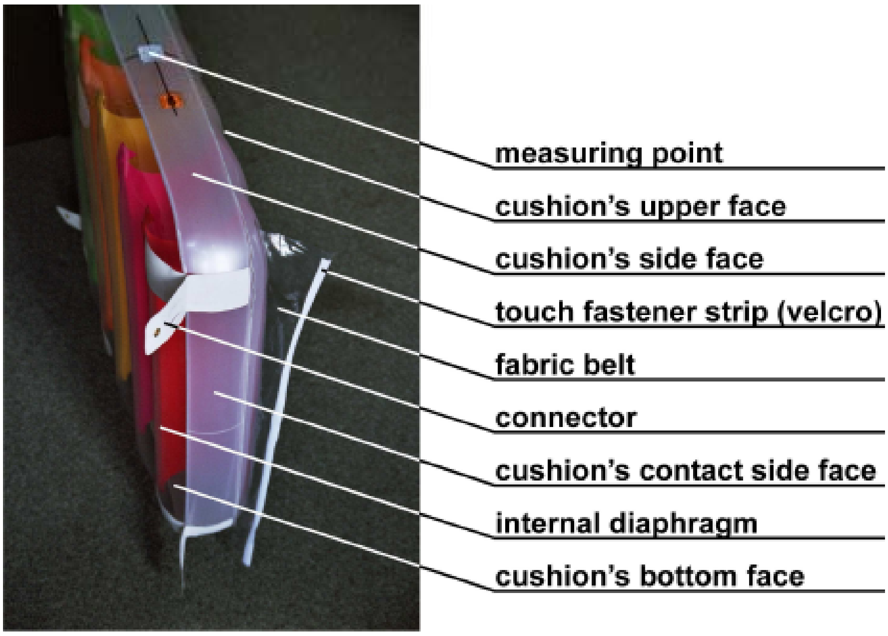

Figure 2: Structure of inflated cushion used in experiment

2.2 Examined configurations of shells

It was assumed that the model would represent a section of cylindrical shell with and without cross-braces. Initial length of the shell should be at least ten times longer that the length of single modular element.

In the initial arrangement, the model presented a string of eleven modular elements. Two models were prepared: M-3 (shell without cross-braces) and M-4 (shell with cross-braces).

Model M-3 was composed of eleven cushions and tensioned cable, without cross-braces while model M-4 was composed of eleven cushions with cross-braces and tensioned cable. Figure 3 presents geometry of the model M-3 before erection and its expected geometry after erection and Fig. 4 – geometry of model M-4 before and after erection.

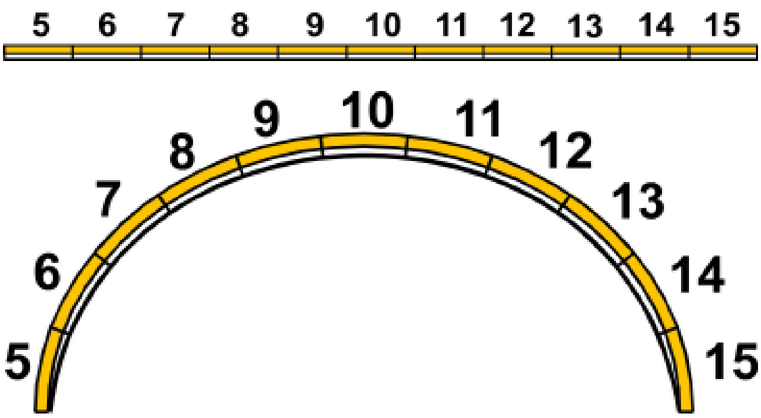

Figure 3: Geometry of model M-3 before and after erection (expected)

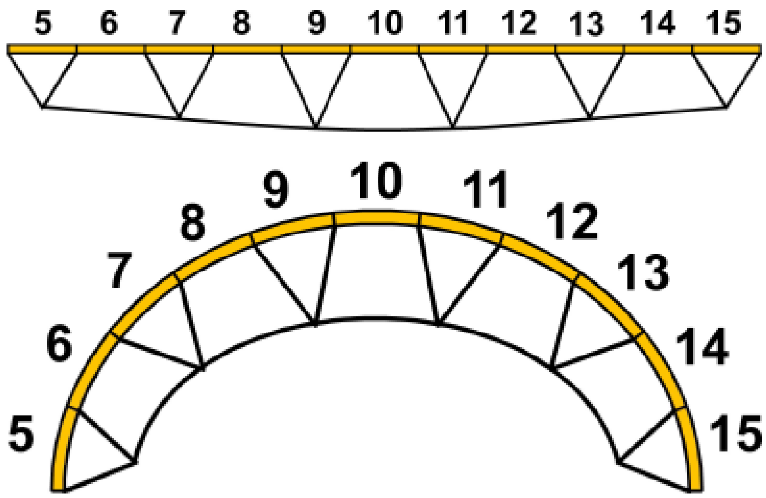

Figure 4: Geometry of model M-4 before and after erection (expected)

2.3 Course of experiment

Experiment was performed in three stages. At the first stage, models M-3 and M-4 were assembled and fitted with tensioned cable and cross-braces. A 6 mm polyethylene fiber rope was used as tensioned member and 20/1 mm PVC pipes were used as cross-braces.

Models were erected up to approx. 50% reduction of initial span. Additionally, model M-4 after erection was loaded at the central point by force Q=0.03 kN.

Survey was executed by means of infrared rangefinder (Zeiss Elta S20). A measuring point – the target for measuring equipment, made of holographic foil, was placed on cushion's side face, Fig. 5. Survey covered initial and final geometry of models at every stage of experiment. An angle and distance to the measuring base was recorded.

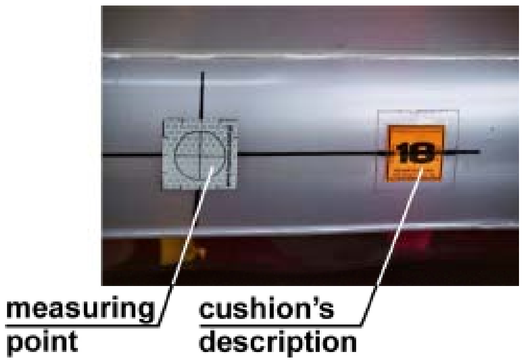

Figure 5: Measuring point on the cushion's side face

2.4 Results of surveying

Recorded results of surveying are presented below. Figure 6 presents comparison of shapes of models M-3 and M-4 after erection and deflected shape of loaded model M-4.

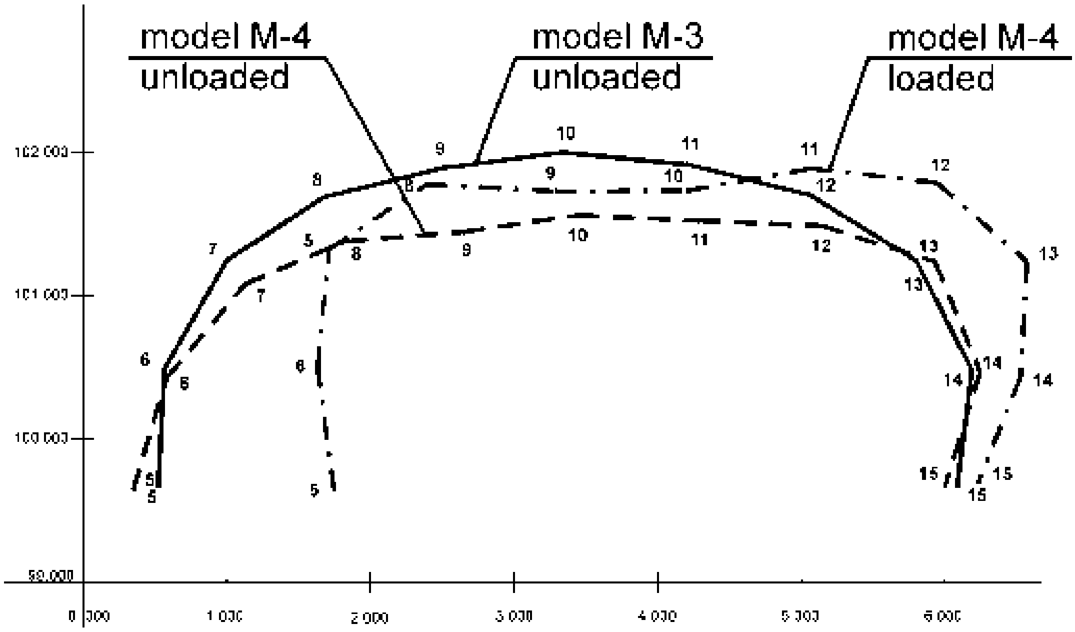

Figure 6: Curves of deformation of models M-3 and M-4

2.5 Conclusions from the initial experiments

The study confirmed the validity and usefulness of the overall design of the system. However, several errors were noted in the experiment. Most of them resulted from rough technical means used for preparation of models, but also a significant problem with the details of the adopted technical solutions has been noted. According to assumptions, the top layer of the modular inflated shell must be able to sustain bending moment. This requires that the upper cord is continuous, and the side surfaces of the cushions are fully touching. An outline of transmission of forces between cushions is shown on Fig. 7.

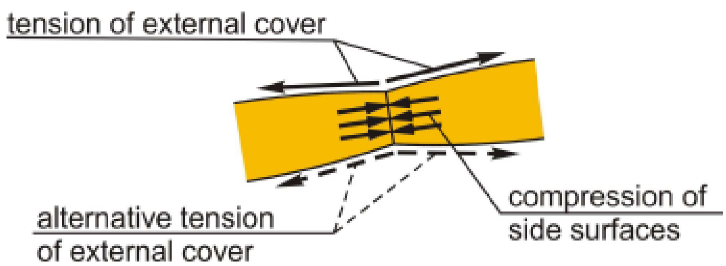

Figure 7: Schematic diagram of transmission of forces between cushions

Tested connections assured only continuity of the upper layer of fabric, while side surfaces – deformed by the air pressure – constituted hinge connections. This, in addition to the fact that the connection between the cable at the lower cord and the cross braces is sliding connection caused instability of the tested model. It’s clearly visible on Fig. 8.

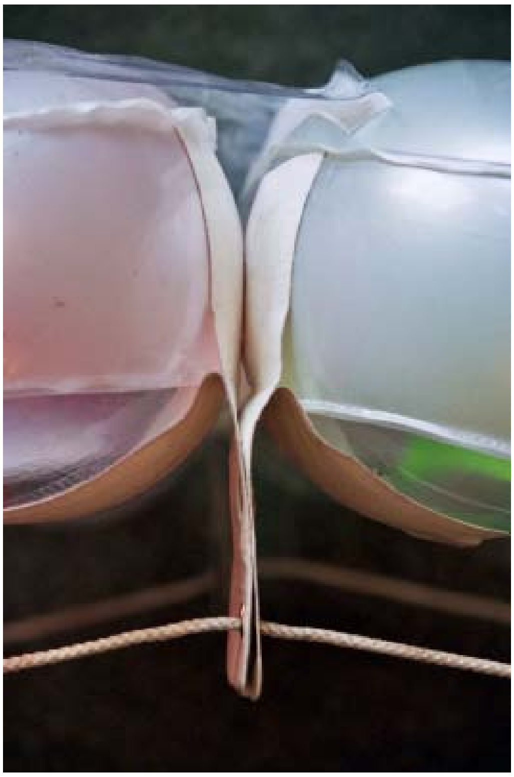

Figure 8: “Hinge” contact of side surfaces

3 INITIAL EXPERIMENTAL RESEARCH

To resolve problem of hinge connection between cushions, new models have been developed and tested. New solution forced full contact of the side surfaces of the cushions by means of using rigid panels. Also, a continuity of the upper cord was increased by use of screw connectors in the rigid panels instead of velcro-tape connectors used previously.

3.1 Description of the improved models

Unlike before, the cushions were made specifically for the purpose of this experiment. Dimensions of each cushion are 100×100×40 cm. They are made of 0.30 mm PVC foil, bonded by means of high frequency welding. One internal diaphragm is placed in the center of the cushion. The most important modification is the use of additional flat pockets on the cushion side surfaces. A rigid panel is inserted into these pockets, which ensures the flatness of the surface. Cushions are equipped with an air valve placed on its bottom face.

Rigid panels (10 mm plywood) inserted into the pockets are screwed together by standard screws M12. Figure 9 presents modified connection of two cushions.

Figure 9: Modified connection of two cushions

3.2 Course of experiments

Experiment with modified cushions was related to the previous experiment. Two models were tested, named respectively M-3’ and M-4’. Models were erected up to approx. 50% reduction of initial span. No additional loading was applied. Other fittings, cables, cross-braces etc. were the same as previously.

3.3 Results of surveying

Behavior of the inflated shells composed of modified cushions has significantly changed comparing to the shells composed of unmodified cushions. No hinge joints were observed and no local instabilities occurred. Curvature of both tested models was smooth and almost symmetrical. Recorded results of surveying are presented on Fig. 10.

4 CONCLUSIONS

Modification of the connection between cushion has significantly affected the behavior of the shell. Although the test models were still very simple and require further improvement of production technology, results of the experiments can be used for further analyze the modular inflated structures.

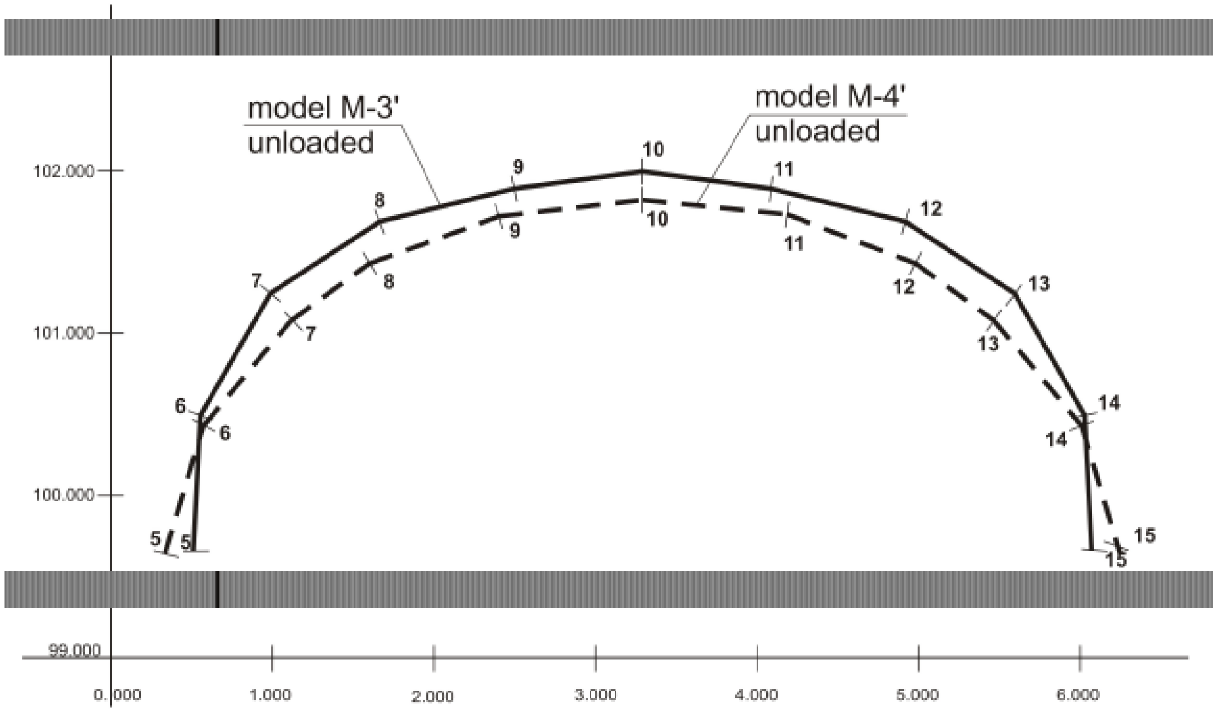

Figure 10: Curves of deformation of models M-3', and M-4'

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